Materials for chairside CAD/CAM–produced restorations

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The interest in fabricating restorations using milling systems continues to grow worldwide. Most of the recent system introductions have been in the area of laboratory-based systems, while CEREC 3 (Sirona Dental Systems GmbH, Bensheim, Germany) is the only chairside system available. The promise of accurate, esthetic restorations delivered rapidly to the patient has many benefits for clinicians, patients and dental laboratories. Although the machining system is the primary facilitator in this scheme, the milled materials ultimately may determine the long-term success or failure of the system. Materials fabricated for use in computer-aided design/computer-aided manufacturing (CAD/CAM) systems must be able to be milled rapidly, resist machining damage

ABSTRACT

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Background and Overview. Although the use of computer-aided design/computer-aided manufacturing (CAD/CAM) seems to be a recent addition to the dental restorative armamentarium, this concept was first investigated more than 35 years ago. CEREC (Sirona Dental Systems GmbH, Bensheim, Germany) was the first and is the only available chairside system, and it has more than 20 years of use in the dental office. The initial concept had three tenets: esthetic ceramic reconstruction, a single patient visit and minimal tooth reduction (inlays and onlays instead of crowns). The author reviews the materials used for CAD/CAM–fabricated restorations. The structure, properties and clinical success of the materials for full-contour chairside restorations, as well as laboratory-based high-strength all-ceramic restorations are presented.

Results. CAD/CAM restorations have demonstrated clinical success owing to a combination of improvements in materials with advances in CAD/CAM systems. Full-contour ceramic restorations fabricated chairside may reinforce the tooth, providing good long-term clinical success. High-strength milled restorations allow for the use of all-ceramic restorations for multiple-unit posterior and anterior bridges.

Clinical Implications. Examination of the structure, properties and clinical results of CAD/CAM materials supports their use in routine dental practice.

Key Words. Computer-aided design/computer-aided manufacturing; zirconia; ceramic.

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and be finished easily (for example, polished, stained or glazed) before placement. Laboratory-based systems also may be used to fabricate high-strength ceramic framework materials, and some systems also may mill metals such as titanium or noble or base metals. These frameworks then must be veneered in a conventional manner—by hand—using porcelain powders or pressed using prefabricated ingots.

CHAIRSIDE MATERIALS

In addition to being able to deliver a restoration in a single visit, CEREC 3 uses materials that have several benefits for patients with respect to wear kindness, longevity and reinforcement of the tooth. CEREC 3 is able to fabricate full-contour restorations (inlays, onlays, crowns and veneers) from a variety of blocks. Several materials are available for use with both CEREC 3 and CEREC inLab (Sirona Dental Systems GmbH) dental laboratory-based systems. These include two types of feldspathic porcelain-based ceramics: Vitablocs Mark II (Vita Zahnfabrik, Bad Säckingen, Germany) and ProCAD (Ivoclar Vivadent, Schaan, Lichtenstein) blocks. A resin-based composite block called Paradigm MZ100 (3M ESPE, St. Paul, Minn.) is a factory-processed version of Z100 Restorative (3M ESPE).

The manufacturers fabricate these materials in a reproducible manner. The reliability of the materials may be enhanced owing to the reproducibility of the manufacturing process, which is a constant. The blocks are produced continuously in the same manner, which results in a dense, high-quality material. Conventionally processed restorations, which also are high quality, are fabricated by hand, which may affect their reliability with respect to mechanical and esthetic properties. This is demonstrated in electron micrographs of pressed, hand-built and block porcelain-based ceramics (Figure 1). Numerous pores can be seen in the cross-sections of the pressed and hand-built restorations, whereas the block material is free of pores. Block materials for other CAD/CAM systems designed for full-contour restorations generally have compositions similar to the materials available for CEREC 3.

Vitablocs Mark II blocks are fabricated using fine-grained powders that produce a nearly pore-free ceramic with fine crystals. This results in improved polishability, decreased enamel wear and increased strength. The strength of this material is approximately 130 megapascals when polished. It may, however, be about 160 MPa or higher when glazed, which is about twice as strong as conventional feldspathic porcelains, and somewhat higher than many pressable materials.[1,2] The ceramic can be acid-etched and cemented easily with resin-based composite. The material has excellent esthetic qualities and can be characterized (that is, have the color match to the existing tooth improved by adding surface colorants commonly referred to as stains) using external stains and a porcelain add-on kit. ProCAD blocks are similar to IPS Empress pressable materials (Ivoclar Vivadent) in structure and properties. ProCAD blocks also have a fine leucite crystal structure (about 5-10 micrometers in size) and may be further characterized using external stains. Strength properties are similar to those of Vitablocs Mark II blocks. Paradigm MZ100 is a resin-based composite with micrometer and submicrometer zirconia-silica fillers. Its block form has mechanical properties superior to those of the conventional Z100 Restorative direct resin-based composite, as well as to other direct resin-based composites. All of these blocks have a fine-particle–sized microstructure that helps resist machining damage, improve mechanical properties, decrease polishing time and improve wear kindness of the finished restoration. Many manufacturers are redesigning their porcelains to create fine-particle–sized veneering materials.

The reliability of the materials used in CAD/CAM systems may be enhanced owing to the reproducibility of the manufacturing process, which is a constant.

One concern about using block materials is that they are monochromatic. The porcelain materials can be stained and glazed just like any other ceramic material. Most pressable restorations are pressed to full contour using a monochromatic ingot and then stained and glazed. Furthermore, a variety of block shades are available to match the patient's natural dentition, and these materials exhibit a "chameleon" effect in that they tend to blend in with the surrounding tooth structure. If a clinician still is concerned about the monochromatic nature of these blocks, he or she could try Vitablocs TriLuxe (Vita Zahn-

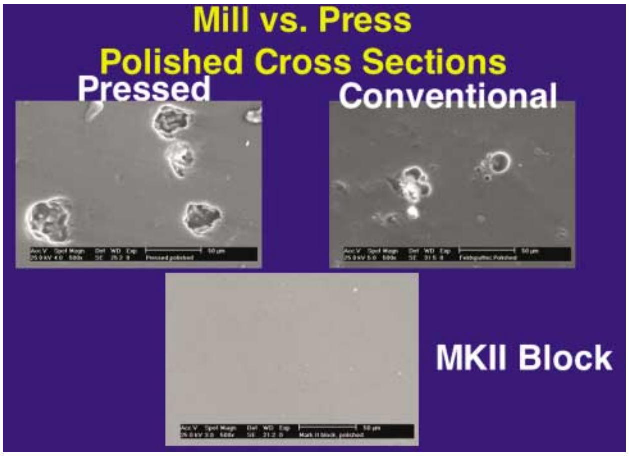

Figure 1. Electron micrographs of a pressed porcelain, conventional (hand-built) porcelain and Vitablocs Mark II (Vita Zahnfabrik, Bad Säckingen, Germany) block. Note the absence of porosity in the Vitablocs Mark II block. MKII: Vitablocs Mark II.

Figure 2. Vitablocs TriLuxe (Vita Zahnfabrik, Bad Säckingen, Germany) block has increasing degrees of chroma. Image of Vitablocs TriLuxe Block reproduced with permission of Vident, Brea, Calif.

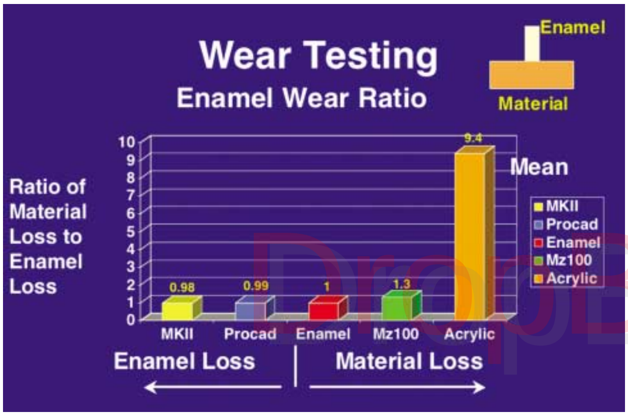

Figure 3. In vitro human enamel wear test of Vitablocs Mark II (Vita Zahnfabrik, Bad Säckingen, Germany), ProCAD (Ivoclar Vivadent, Schaan, Lichtenstein), Paradigm MZ100 (3M ESPE, St. Paul, Minn.), enamel and acrylic. A ratio close to 1 indicates wear similar to tooth against tooth. MKII: Vitablocs Mark II. Sources: Abozenada and colleagues,[4] McLaren and colleagues[5] and McLaren and Giordano.[6]

fabrik), which contains a graded variation in color saturation (three shades). The middle layer (body) has a regular chroma; the top layer (enamel) has a low, less intense chroma with high translucency; and the lower layer (neck) has the highest chroma and low translucency (Figure 2). Using Vitablocs TriLuxe makes it possible to copy the optical characteristics of a natural tooth, including translucency and color intensity, which may enhance the integration of the restoration into the remaining natural dentition.

Clinicians often have been concerned about the milling process and the use of ceramic materials. These concerns generally involve the strength of the ceramic, the ability to finish the ceramic, the possibility of machining damage, fit and enamel wear. Several independent studies have addressed these concerns.

Enamel wear has been a concern when using ceramics. The surface finish and microstructure of materials greatly influence enamel wear. If the surface is polished or glazed and if the microstructure is fine-grained, then tooth enamel wear is minimized. A number of studies show that CEREC materials' level of tooth enamel wear essentially is equivalent to that of tooth enamel against tooth enamel if the surface is polished or glazed.[3-6] Researchers tested these materials against natural human enamel in a standard abrasion system and recorded the volume loss of materials (Figure 3).[4-6] A "wear ratio" was obtained, which normalized the data relative to enamel versus enamel to account for natural variations in tooth structure. The closer the value of the test material was to 1, the more the material behaved like natural tooth structure with respect to enamel abrasion. The ratios of both the Vitablocs Mark II and ProCAD blocks were close to 1, whereas the Paradigm MZ100 ratio was slightly higher, indicating some material loss but that wear kindness still was good.

Machining alone decreases the strength of the ceramics; however, ceramics can be polished using rubber wheels and diamond paste to produce a surface that is superior to glazing, which brings the strength back to at least that of the "as-received" material. Further improvements in strength of about 160 MPa or higher can be achieved by a combined polishing and overglazing procedure that uses polishing, staining or glazing materials designed specifically for these blocks. Paradigm MZ100 also can be polished easily. One advantage of the resin-based composite is that

there is less of an effect of machining on the finish. The fact that each of these blocks is manufactured under the same conditions produces a more homogeneous, dense and reliable ceramic than what often can be produced conventionally in a dental laboratory. A study of Vitablocs Mark II compared with conventional porcelains demonstrated this improved reliability.[7]

Investigators have studied the fit of crowns milled on CEREC 3 using ceramic blocks for the effects of preparation convergence angle and cement space settings.[8] When the investigators used a setting of 30 µm, which is equivalent to most cement thickness, they found that the convergence angle had no effect on the margin gap, which averaged about 50 µm. Other studies measured a margin gap of about 50 µm.[9,10] These openings are well within the 80 to 100 µm that can be detected clinically and less than gaps found in a study of metal-ceramic restorations processed at dental laboratories.[11]

The properties of the ceramic closely match those of enamel, and the bonded enamel-ceramic-dentin complex may mimic that of natural tooth structure.

Definitive proof of success is in clinical trial data. Martin and Jedynakiewicz[12] summarized 29 trials conducted over one to 10 years (mean 4.2 years) and found that nearly 3,000 inlays had a success rate of 97.4 percent. The material used in most of the clinical studies was Vitablocs Mark II, but ProCAD was used in some studies. In a study by Mörmann[13] examining only Vitablocs Mark II inlays, the success rate after six years was about 99 percent. In a separate clinical trial[14] of 18 Vitablocs Mark II crowns, only one failure occurred after a service period of two to five years. In another study, Posselt and Kerschbaum[15] placed 2,328 ceramic inlays in 794 patients; the survival rate was 95.5 percent after nine years. This survival rate compares favorably with those of conventional castable glass ceramics, which showed a 5 percent failure rate for IPS Empress inlays after five years and an 11.6 percent failure rate for IPS Empress crowns after six years, with a predicted rate of 14.5 percent after seven years; most failures were in canines and molars.[16,17] Hickel and Manhart[18] analyzed the longevity of multiple restorative materials by calculating the mean failure rate per year of restorations from multiple clinical trials. They found that the cast gold mean failure rate was 1.2 per year, the CEREC-generated restoration mean failure rate was 1.1 per year, the direct composite mean failure rate was 2.2 per year, the indirect composite mean failure rate was 2.0 per year, and the amalgam mean failure rate was 3.3 per year. A study of Paradigm MZ100 inlays over three years evaluated fracture, sensitivity, color stability, margin integrity and anatomical form/wear.[19] Researchers scored each restoration on a standardized scale and found that more than 95 percent of the restorations had a score in the highest level.

The data indicate that CEREC-milled restorations are clinically reliable. One of the reasons for the clinical success may have been the technology's ability to restore the mechanical properties of the tooth using the bonded and milled materials. The stiffness of a tooth can be restored to almost its original level (96 percent) by using bonded ceramics.[20,21] The properties of the ceramic closely match those of enamel, and the bonded enamel-ceramic-dentin complex may mimic that of natural tooth structure. In a recent study examining load to failure of teeth restored with Vitablocs Mark II, ProCAD and a conventional feldspathic porcelain, the teeth restored with the milled crowns failed at a load equivalent to that of unrestored natural teeth, which was significantly higher than that of the teeth restored with conventional porcelain.[22]

LABORATORY-BASED FRAMEWORK MATERIALS

Dental laboratory systems are designed to produce multiple-unit restorations using high-strength ceramic frameworks or metal frameworks. Most laboratory-based CAD/CAM systems are designed to produce only ceramic frameworks. Partially stabilized zirconia is the strongest, and may be the most popular, form of ceramic. It is milled in some form by nearly every laboratory-based CAD/CAM system. A few systems, including DCS (Popp Dental Laboratory, Greendale, Wis.), also mill metals such as titanium or base metals for frameworks and even custom implant abutments such as the TurboDent System (U-Best Dental Technology, Anaheim, Calif.) and Procera (Nobel Biocare, Goteborg, Sweden) systems.

CEREC inLab framework materials. In

addition to CEREC 3, CEREC inLab extends the reach of CAD/CAM to the fabrication of high-strength all-ceramic restorations for crowns, as well as multiple-unit bridges. Several materials are available for frameworks using CEREC inLab, including the Vita In-Ceram (Vita Zahnfabrik) materials including Vita In-Ceram Alumina cubes, IPS e.max CAD (Ivoclar Vivadent) glass-ceramics and yttria partially stabilized zirconia materials (so-called "pure" zirconia). These partially stabilized zirconia materials are the Vita InVizion system (Vita In-Ceram YZ [yttrium-stabilized] zirconia) and IPS e.max ZirCAD (Ivoclar Vivadent).

Vita In-Ceram materials belong to a class known as "interpenetrating phase composites."[23] They involve at least two phases that are intertwined and extend continuously throughout the material. These materials possess improved mechanical and physical properties relative to the individual components, owing to the geometric and physical constraints that are placed on the path that a crack must follow to cause fracture. Porous blocks of Vita In-Ceram materials are milled to produce a framework. Then the blocks are infused with a glass in different shades to produce a 100 percent dense material, which then is veneered with porcelain. Vita In-Ceram is available in three types, designed for specific regions of the mouth. Vita In-Ceram Spinell is the most translucent with moderately high strength (350 MPa) for anterior crowns, followed by Vita In-Ceram Alumina with high strength (450-600 MPa) and moderate translucency for anterior bridges and anterior and posterior crowns, and Vita In-Ceram Zirconia with high strength (700 MPa) and lower translucency for three-unit anterior and posterior bridges and anterior and posterior crowns.

Clinical trials of Vita In-Ceram Alumina restorations, including anterior and posterior crowns and three-unit anterior bridges have demonstrated a high success rate of 95 to 98 percent after seven to 10 years.[24-27] Clinical data on Vita In-Ceram Zirconia are limited to those reported by Sadoun[28] who found a 98 percent success rate in three-unit posterior bridges over seven years. There is clinical evidence to demonstrate that the Vita In-Ceram materials perform at least as well as porcelain-fused-to-metal (PFM) restorations. In studies of PFM bridges, success rates were approximately 95 to 98 percent at five years and dropped to about 84 to 87 percent at 10 years.[29-31]

Partially stabilized zirconia is one of the materials that allows for the production of reliable multiple-unit, all-ceramic restorations for high-stress areas, such as the posterior region of the mouth. Owing to its high strength and toughness, zirconia may be a universal ceramic restorative material that can be used anywhere in the mouth. There is some confusion as to which manufacturer's zirconia does what and why zirconia might be advantageous.

Zirconia may exist in several crystal types (phases), depending on the addition of minor components such as calcia, magnesia, yttria or ceria. Specific phases are said be stabilized at room temperature by the minor components. If about 8 to 12 percent of a component is added, a fully stabilized cubic phase, such as cubic zirconia, can be produced. If smaller amounts (3-5 weight percentage) are added, then a partially stabilized zirconia is produced. The tetragonal zirconia phase is stabilized at room temperature; however, under stress, the phase may change to monoclinic phase, with a subsequent 3 percent volumetric size increase. This dimensional change takes energy away from the crack and can stop its growth and is called "transformation toughening" (Figure 4). Also, the volume change creates compressive stress around the particle, which provides a further inhibition to the crack's growth. Natural teeth often contain many cracks in the enamel that do not propagate through the entire tooth. These cracks can be stopped by the unique interface at the enamel-dentin junction and enamel-crystal microstructure.

The ability to stop the cracks as they enter the zirconia core structure mimics the effect seen in natural teeth. Furthermore, the core may be able to resist high-stress areas internally such as sharp line angles in the tooth preparation, grinding damage during internal adjustment, and stresses generated by chewing or thermal changes in the mouth. Transformation toughening helps give the zirconia its excellent mechanical properties: high flexural strength (≈1.0 gigapascals) and toughness (7-8 MPA × meters to the one-half power). Another beneficial property is its good biocompatibilty.

The mechanical properties may allow for decreased coping thickness and connector sizes. Failure in all-ceramic bridges often occurs at the connectors, so connector sizes must be larger, particularly for lower strength frameworks. However, both the connector size and the coping thick-

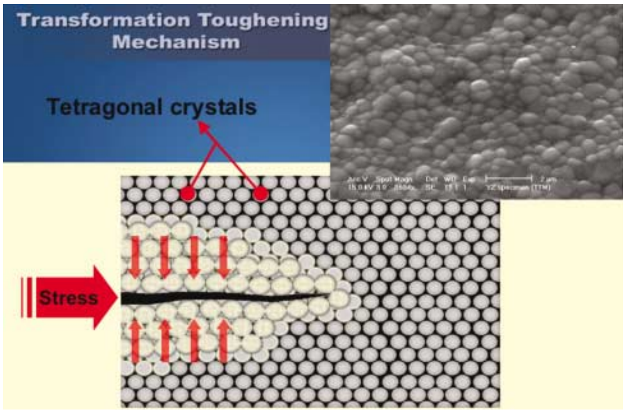

Figure 4. Transformation toughening occurs as tetragonal phase converts to the larger monoclinic phase under stress. This may prevent crack propagation. An electron micrograph of Vita In-Ceram YZ (Vita Zahnfabrik, Bad Säckingen, Germany), shows the fine submicrometer crystalline structure.

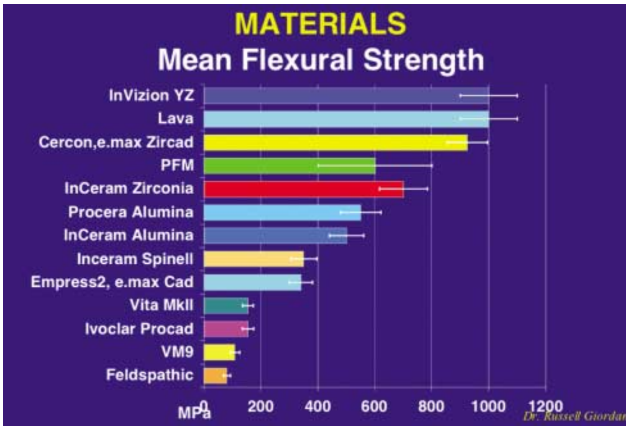

Figure 5. Flexural strength of various restorative materials: Vita InVizion (In-Ceram) YZ (Vita Zahnfabrik, Bad Säckingen, Germany), Lava (3M ESPE, St. Paul, Minn.), Cercon Zirconia (Dentsply, York, Pa.), IPS e.max ZirCAD (Ivoclar Vivadent, Schaan, Lichtenstein), Vita In-Ceram Zirconia (Vita Zahnfabrik), Procera (Nobel Biocare, Goteborg, Sweden), Vita In-Ceram Alumina (Vita Zahnfabrik), Vita In-Ceram Spinell (Vita Zahnfabrik), IPS Empress 2 (Ivoclar Vivadent), IPS e.max CAD (Ivoclar Vivadent), Vitablocs Mark II (Vita Zahnfabrik), ProCAD (Ivoclar Vivadent), Vita VM 9 (Vita Zahnfabrik) and feldspathic. PFM: Porcelain-fused-to-metal. Vita MKII; Vita Mark II. MPa: megapascals. Sources: Seghi and Sorensen,[1] Giordano and colleagues[2] and McLaren and Giordano.[6]

ness of zirconia frameworks approach those of conventional metal restorations. Also, longer span bridge frameworks (four or more units) can be fabricated. The Vita In-Ceram YZ and IPS e.max ZirCAD blocks are partially fired to produce a chalky block that is milled easily. The framework is milled oversized to account for firing shrinkage of 20 to 30 percent and fired at about 1,500 C to fully densify the zirconia. Each block has a bar code that tells the computer the density at which to properly mill the framework oversized. Systems such as Lava (3M ESPE), Cercon Zirconia (Dentsply, York, Pa.) and Everest (KaVo Dental, Biberach, Germany) use this approach. The DCS system mills prefired zirconia; it already is fully dense, so an additional firing step is not required. However, owing to the toughness of zirconia, it takes about two hours to mill a single coping as opposed to about 15 minutes for the "chalky" blocks. Vita In-Ceram YZ and Lava frameworks may be shaded intrinsically using colorant solutions that can help eliminate the need for any opaque porcelain layer or liner and enhance the esthetic result. Zirconia is one material that cannot be used easily without CAD/CAM techniques. Zirconia has excellent clinical success rates.[32]

Two recent additions to the armamentarium are IPS e.max CAD and Vita In-Ceram Alumina cubes. IPS e.max CAD is a lithium disilicate glass ceramic similar to IPS Empress 2 (Ivoclar Vivadent) in strength (320 MPa) and microstructure. In block form, it is only partially crystallized to facilitate machining. After milling, the framework is fired at 850 C for 0.5 hour, which completes the crystallization. Vita In-Ceram Alumina cubes are in a chalky form similar to those of Vita In-Ceram YZ; they are milled oversized and sintered to full density. Vita In-Ceram Alumina has a fine particle size of about 1 µm and a strength of about 600 MPa, and it is designed for anterior and posterior single-unit crowns, as well as anterior three-unit bridges. IPS e.max CAD may be used for three-unit bridges up to the first premolar, as well as single-unit crowns, inlays and onlays. Figure 5 shows a comparison of the various restorative materials' strengths.[1,2,6]

Strength values. The clinical ramifications of strength values may be assessed by combining strength data with the clinical trial data on all-ceramic restorations. Vita In-Ceram Alumina success rates for anterior bridges and anterior and posterior crowns ranged from 95 to 98 percent after seven years. Before Vita In-Ceram Zirconia or partially stabilized zirconia (Vita In-Ceram YZ, IPS e.max ZirCAD, Lava) was available, some experimental trials used Vita In-Ceram Alumina to fabricate three-unit posterior bridges, which resulted in a lower success rate (about 80 percent).[33] Although the manufacturer never recommended Vita In-Ceram Alumina for three-unit posterior bridges, these clinical data helped provide a baseline for strength requirements for posterior all-ceramic bridges. The success rates for Vita In-Ceram Zirconia are about 97 percent after seven years.[1,2,6] Therefore, it can be concluded

that materials with values equal to or greater than that of Vita In-Ceram Zirconia will have high success rates for posterior bridges. In addition, bridges made from partially stabilized zirconia will have high resistance to stress in the mouth and may have an even better longevity than Vita In-Ceram Zirconia. Furthermore, it is possible to fabricate longer span bridges and use smaller connectors and thinner copings, which allows for less tooth reduction.

In addition to these high-strength frameworks, researchers have designed fine particle veneering porcelains to further enhance the benefit to the patient of using a high-strength, all-ceramic restoration. Many veneering porcelains have a coarse structure with particle sizes of 50 to 100 µm. Ceramics processing science has shown that refining the particle size improves the mechanical properties of the material. There also is a significant added benefit: improved wear kindness to the opposing natural dentition. Many clinicians have seen or heard about teeth being worn away by porcelain. With these new porcelains, wear is equivalent to that of tooth against tooth. The fine structure also makes these materials easy to polish intraorally, so that a smooth finish can be obtained even if adjustments are required at the time of insertion. Examples of this are Vita VM 7 (Vita Zahnfabrik) porcelain used with Vita In-Ceram and Vita VM 9 (Vita Zahnfabrik) porcelain used to veneer Vita In-Ceram YZ. When they tested these porcelains against natural tooth structure, researchers found that the Vita VM 7 porcelain produced the least enamel wear and that the Vita VM 9 porcelain was wear-kind (Figure 6).[4-6] The dramatic effect of particle size on enamel wear is demonstrated by the Vita VM 7 material, which has the same chemical composition as the old Vita Alpha Porcelain (Vita Zahnfabrik) but a much smaller particle size (2 to 5 µm versus 20 to 30 µm).

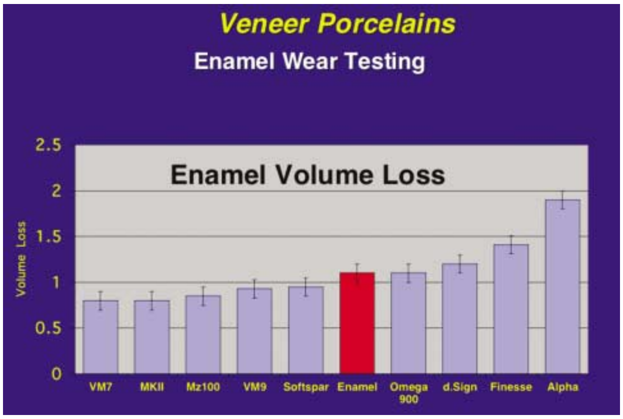

Figure 6. In vitro wear test of various materials against human enamel: Vita VM 7 (Vita Zahnfabrik, Bad Säckingen, Germany), Vitablocs Mark II (Vita Zahnfabrik), Paradigm MZ100 (3M ESPE, St. Paul, Minn.), Vita VM 9 (Vita Zahnfabrik), Softspar (Jeneric-Pentron, Wallingford, Conn.), enamel, Omega 900 (Vita Zahnfabrik), d.sign (Ivoclar Vivadent), Finesse (Dentsply Ceramco, York, Pa.) and Vita Alpha Porcelain (Vita Zahnfabrik). Data are presented in terms of tooth enamel volume loss in cubic millimeters. VMII: Vita Mark II. Sources: Abozenada and colleagues,[4] McLaren and colleagues[5] and McLaren and Giordano.[6]

CONCLUSIONS

It is the goal of any medical procedure to provide the best treatment for the patient while following the Hippocratic oath: "First, do no harm." As dentists, we are challenged to restore function, while providing a highly esthetic result. The choices available for esthetic restorations are expanding continually as more private and public research is aimed at improving clinical results. An examination of material properties should lead us to select those systems engineered to provide the patient with the best clinical outcome with respect to esthetics, function, longevity and compatibility with surrounding natural tissues. Analysis of clinical and laboratory data demonstrates that machined restorations are a reliable, esthetic alternative that may provide a superior outcome relative to conventional fabrication systems. ■

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